Real-time Operating Systems and Systems Programming

Introduction
Lecture 1

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About the Course

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Expectations

- Familiarity with C programming language
  - There will be a test on October 2
- Some familiarity with command-line helps

Test

- October 4.
- Devious puzzles
- Everything you can do without libraries
  - C keywords
  - Precedence
  - Pointers and arrays
- Goal is to brainwash you
  - Tricks your brain into remembering things
  - Gives extra points for the exam

Extremely nasty C (test is easier)

```
typedef unsigned char B;char*x[]={
#include "dict.h"
0};typedef struct L{B*s;struct L*n;}L;
L*h[128],*l[128],*s[128],Z[sizeof x/sizeof*x],*F=Z;int c[256],m,a=1;
int k(B*q){int g=0;B*p=q;while(*p)g|=!c[*p++]--;return g-1&p-q;}
void u(B*p){while(*p)c[*p++]++;}
void S(int N,int r,int t,L*W){L*w;int i,n;
 for(n=r<N?r:N;n>0;n--)for(w=n==N?W:h[n];s[t]=w;u(w->s),w=w->n)if(k(w->s))
  if(n==r){if(t==m-1)for(i=a=0;i<=t;i++)printf("%s%c",s[i]->s,i<t?' ':'\n');}
  else if(t<m-1)S(n,r-n,t+1,s[t]=w);}
int main(int C,B**A){int i=0,g,n=0;B*p;while(--C)for(p=*++A;n<127&&*p;)c[*p++]++,n+
   +;
 for(;p=x[i++];u(p))if(g=k(p))(l[g]=*(l[g]?&l[g]->n:&h[g])=F++)->s=p;
 while(++m<128)S(127,n,0,h[127]);
 return a;}

                    - Peter Klausler, IOCCC 2006 (http://www.ioccc.org/)
```

Grades

- Programming project(s) (40%)
  Small practice tasks
  At least one larger program
- Exam (60%)
  Terminology, some functions, code reading, coding on paper

Topics

- Hardware IO; interrupts
- Stack, heap
- Signals, threads, processes, mutexes
- Scheduling
- Standard IO, file, dir management
- Programming an Operating System
- Networking
- Optimizing, security, Localization

C keywords

- Types
  - `char double enum float int long short struct union void`
- Parameters to variables
  - `auto const extern register signed static unsigned volatile`
- Flow control
  - `break case continue default do else for goto if return switch while`
- Operators
  - `sizeof, typeof`

Operator precedence

```
>>    ()   []  ->   .
<<    !  ~  ++  -- + - * & (type) sizeof
>>    *  /  %
>>    +  -
>>    <<  >>
>>    <  <=  >  >=
>>    ==  !=
>>    &
>>    ^
>>    |
>>    &&
>>    ||
<<    ? :
<<    =  +=  -=  *=  /=  %=  &=  ^=  |=  <<=  >>=
>>    ,
```

Maths and Logic

```
                 (things I want done before maths)

>>   *  /  %     (maths)
>>   +  -
                 (things between maths & logic)


>>   &
>>   ^
>>   |           (logic)
>>   &&
>>   ||

                 (things I want after logic)
```

Really important things

```
>>   ()   []  ->  .                  {language constructs}
<<   !  ~  ++  -- + - * & (type) sizeof  {unary}
>>   *  /  %                               {maths
>>   +  -                                  }



>>   &                                     {logic
>>   ^
>>   |
>>   &&
>>   ||                                    }
```

What goes between maths and logic?

```
>>    ()   []  ->  .                    {language constructs}
<<    !  ~  ++  -- + - * & (type) sizeof  {unary}
>>    *  /  %                              {maths
>>    +  -                                 }

>>    <  <=  >  >=                         {comparison}
>>    == !=                                {equality}
>>    &                                    {logic
>>    ^
>>    |
>>    &&
>>    ||                                   }
```

Finally

```
>>    ()   []  ->  .
<<    !  ~  ++  -- + - * & (type) sizeof
>>    *  /  %
>>    +  -
>>    <<  >>
>>    <  <=  >  >=
>>    ==  !=
>>    &
>>    ^
>>    |
>>    &&
>>    ||
<<    ? :
<<    =  +=  -=  *=  /=  %=  &=  ^=  |=  <<=  >>=
>>    ,
```

Variables

- Name to an address.
- Type says amount of memory to reserve
- Must be declared before use

Real-Time Systems

- Hardware or software which has a time constraint for reactions
- For our purposes, also embedded systems
  - What would be the difference?

Some reading

- Main books:
  - Brian W. Kernighan, Dennis M. Ritchie *The C Programming Language, Second Edition*, Pretince Hall 1988
  - Randal E. Bryant and David R. O'Hallaron *Computer Systems: A Programmer's Perspective (CS:APP)*, Prentice Hall, 2003
  - has a newer edition too

Characteristics

- Specified limit on system response latency
- Event-driven scheduling
- Low-level programming
- Software coupled to special hardware
- Volatile Data
- Multi-tasking implementation
- Unpredictable environment
- Runs continously
- Life-critical applications

Example: Anti-lock brakes

- Must prevent locking of wheels while braking
- Inputs: Brake pedal, Wheel rotation
- Actuators: Brakes

Human brain?

- "The human brain runs a Real-Time Operating System. Conscious thought is a low priority task."
  - Bob Cross on c2 wiki
- Real-time system or not?

Pathfinder Rover

- Initially successful: July 4, 1997
- Software resets start
  - Serious data losses
  - Problem: bus overloaded with data
  - Low priority data collection locks the bus, medium priority tasks interrupt it
  - High priority data distribution task fails: cannot get bus
  - Scheduler detects pending high-priority task & resets

Solutions

- Priority inversion: high priority task delayed in a critical section by low priority tasks
- Solution was priority inheritance: low priority tasks entering critical section will inherit the highest priority of waiting tasks
- Solved the Pathfinder reset problem

More examples

- Microwave, dishwasher, toaster
- Cars: cruise control, drive-by-wire
- Computers: peripheral devices, applications
- Planes: auto-pilot, stability, fly-by-wire

Terminology

- System: black box with n inputs and m outputs
- Response time: time between presentation of a set of inputs and the appearance of the corresponding outputs
- Events: Changes of state which cause changes in flow-of-control of a progam
  - Synchronous: events occur at predictable times
  - Asynchronous: events interrupt flow-of-control

State vs Event based

- State based:
  - System constantly reads system inputs and reacts to their combination
- Event based
  - System is in standby and events “wake” it to make it work

Deterministic RTS

- A deterministic RTS: you can determine a unique set of outputs and next state from a given set of possible states and inputs.

Real time Correctness

- Correctness depends on result and the time of delivery.
- Soft – missing some deadlines not a problem
- Firm – missing deadline: result worthless, but not a problem
- Hard – missing a deadline makes result worthless and is a problem

Misconceptions

- "Really fast" is real-time.
  - Might not be predictable enough
- Interactive is real-time.
  - Again: interactive optimized for "average" case.
- Real-time = "Bug free":
  - Often the case, but bug free is wider concept

Static Predictability

- RT system: satisfying time constraints
  - Assumptions about workload and sufficient resources
  - Certified at design time, that all constraints will be met
- For static systems, 100% guarantees can be given at design time
  - Requires immutable workload and system resources
  - System must be re-certified on any change

Dynamic Predictability

- Dynamic systems: not statically defined
  - Systems configurations might change
  - Workload might change
- Dynamic predictability
  - Under appropriate assumptions (sufficient resources)
  - Tasks will satisfy time contstraints

Latency minimization

- Latency is the time between an event and the system's reaction to it.
- We want to minimize latencies
  - For different applications, different latencies are required.
  - 10 ms might be barely enough (probably a dedicated system)
  - 500 ms might be enough (might use an external kernel)

Multiple Requirements

- Real-time
- Power constraints
- Size constraints
- Cost limits
- Security requirements
- Fault tolerance

- *Often conflicting*

New Environments

- Ubiquitous Computing
  - Computers become invisible, so embedded and natural that we use them without thinking of using them.
- Autonomous Computing
  - Self-configurable
  - Self-adapting
  - Optimizing
  - Self-healing